

Artificial Intelligence as a Catalyst for Changes in University-Level Science Education

Konstantinos T. Kotsis^{1,*} ¹ Department of Primary Education, University of Ioannina, Greece* Correspondence: kkotsis@uoi.gr<https://doi.org/10.59652/jetm.v3i3.618>

Abstract: Artificial intelligence is widely seen not just as a technological advancement in education, but as a catalyst for rethinking the epistemological, pedagogical, and institutional foundations of university-level science instruction. This article is a theoretical and literature-based study that does not present empirical data but instead synthesizes existing research and conceptual frameworks to explore AI's transformative potential. It examines how AI can redefine university-level science education across five interconnected dimensions: cognition, epistemology, pedagogy, institutional design, and ethics. Utilizing recent studies in science education, educational technology, and artificial intelligence, the paper contends that intelligent systems – such as adaptive tutors, learning analytics platforms, and generative models – can facilitate inquiry-based, student-centered learning environments that are congruent with genuine scientific practices. Nonetheless, their integration presents significant issues related to teacher autonomy, algorithmic bias, and institutional equity. The article contextualizes AI within extensive dialogues on knowledge creation and educational reform, promoting a values-oriented strategy that harmonizes technological advancement with humanistic objectives. This work reframes AI as a philosophical lens rather than merely a tool, contributing to the redefinition of science education's future in a swiftly changing digital environment.

Keywords: artificial intelligence; university-level science education; educational technology; inquiry-based learning; pedagogical innovation

1. Introduction

The swiftly changing environment of higher education necessitates a reevaluation and reorganization of university-level science education. As societies face intricate global challenges – such as climate change, pandemics, and the ethical ramifications of emerging technologies – the necessity for graduates possessing not only disciplinary expertise but also critical thinking, adaptive problem-solving abilities, and scientific literacy has escalated. In this context, artificial intelligence (AI) is emerging not only as a technological advancement but as a transformative force capable of instigating profound and systemic alterations in the methodologies of teaching, learning, and comprehending science at the university level.

University scientific education, typically centered on established curricula and lecture-centric methods, frequently fails to embrace pedagogical and epistemological advancements that address the realities of the digital and post-digital age. Notwithstanding the advocacy for student-centered learning, interdisciplinary collaboration, and active inquiry, numerous scientific departments continue to depend predominantly on transmissive teaching approaches that emphasize content coverage rather than conceptual comprehension or epistemic agency (Guerrero & Sjöström, 2024). Students entering university had varied backgrounds, digital competencies, and anticipations for involvement and personalization – expectations frequently unfulfilled by traditional science training. AI, through its capabilities for data-driven adaptation, intelligent feedback, and dynamic representation of scientific processes, creates new opportunities to connect educational methods with learner requirements.

Recent advancements in AI, encompassing machine learning, natural language processing, and generative models, have exhibited significant potential in educational settings. AI-driven systems can facilitate automated tutoring, replicate intricate scientific events, assess

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students' thinking patterns in real time, and provide adaptive scaffolding for varied learners (Luckin et al., 2016; Zhai, 2023). In the realm of scientific education, these advantages closely correspond with pedagogical goals such as inquiry-based learning, formative assessment, and epistemic engagement with authentic issues. The incorporation of AI into science education is neither neutral nor solely a technical undertaking. It necessitates a reassessment of fundamental inquiries regarding knowledge, pedagogy, and the educator's role in an AI-enhanced context.

Despite numerous empirical studies demonstrating the applications of AI in education, a significant gap exists in the theoretical literature that critically examines how AI may serve as a catalyst for epistemological, pedagogical, and institutional transformation specifically in university-level science education. This article fills the void by providing a theoretically informed examination of AI's capacity to transform the objectives, methodologies, and frameworks of science education in higher education. The paper conceptualizes AI not merely as an adjunct to existing systems, but as a disruptive epistemic force that requires a reevaluation of the objectives and methodologies of science education.

This article begins by contextualizing the subject within contemporary theoretical and conceptual frameworks of scientific education and AI. It subsequently examines five interconnected dimensions via which AI can serve as a catalyst for transformation – cognitive, epistemological, pedagogical, institutional, and ethical. The article elaborates on these features, delineating emergent instructional paradigms and examining their larger implications for curriculum design, educator preparation, and institutional policy. The primary objective is to provide a novel paradigm for redefining science education in the AI era – characterized by responsiveness, equity, and intellectual rigor.

2. Conceptual and Theoretical Background

To comprehend how AI can act as a catalyst for transformation in university-level science education, it is crucial to contextualize this discourse within overarching theoretical frameworks that delineate the essence of science learning, the pedagogical objectives of higher education, and the epistemological foundations of AI technologies. This part discusses the conceptual issues confronting science education in modern universities, highlights advancements in AI pertinent to education, and presents theoretical perspectives that advocate for a reevaluation of teaching and learning methodologies in response to these breakthroughs.

University scientific education has traditionally emphasized topic mastery, procedural fluency, and algorithmic problem-solving, often at the expense of critical inquiry, epistemic agency, and interdisciplinary synthesis. Despite enduring critiques from science education researchers, the prevailing pedagogical model continues to be lecture-centered and assessment-driven, frequently sidelining the active construction of knowledge and constraining opportunities for students to interact with the essence and practices of science as a dynamic human endeavor (Fensham, 2022; Aikenhead, 2006). This conventional method is progressively inconsistent with the requirements of a knowledge society that prioritizes adaptability, trans-disciplinary thought, and the ability to critically examine scientific assertions within wider sociotechnical frameworks.

Simultaneously, AI has experienced a significant evolution, transitioning from symbolic systems centered on rule-based reasoning to statistical, data-driven frameworks adept at learning from intricate, high-dimensional inputs. In education, AI has evolved beyond automated grading and basic recommendation systems to include a range of sophisticated technologies, such as virtual teaching assistants, intelligent tutoring systems (ITS), learning analytics dashboards, and generative language models (Holmes et al., 2019). These technologies not only improve efficiency but also transform the epistemic conditions of learning. AI systems can facilitate dialogic exchanges, simulate scientific reasoning processes, and customize scaffolds according to learners' cognitive and emotional profiles, so fostering more contextual and adaptive learning environments.

The incorporation of AI into science education should be conceptualized not merely as a technological capability, but as a locus of educational revolution that addresses issues of knowledge creation, authority, and agency. Sociocultural learning theories, especially those based on Vygotsky's notion of mediated action, provide a valuable framework for understanding the function of AI as a novel category of cognitive artifact. From this viewpoint, AI technologies integrate into the sociotechnical system that facilitates learners' engagement in meaning-making activities, collaborative construction of scientific concepts,

and involvement in disciplinary practices (Barab, 2014). Activity theory, as elaborated by Engeström, contextualizes AI-mediated learning within an extensive framework of cultural instruments, regulations, and communal standards, emphasizing how technological advancements can generate conflicts that lead to significant shifts in educational practices.

Furthermore, transformative learning theory offers a robust framework for comprehending how the integration of AI might confront established beliefs and stimulate profound conceptual transformation. Mezirow (2000) posits that transformative learning transpires when learners critically assess their current frames of reference and embrace more inclusive, discerning, and integrative viewpoints. In a university science context, AI tools that facilitate students' visualization of abstract phenomena, allow hypothesis testing in virtual laboratories, or provide individualized feedback on their conceptual models might work as catalysts for critical reflection and epistemic transformation.

The Technological Pedagogical Content Knowledge (TPACK) framework is a supplementary approach that underscores the amalgamation of topic knowledge, pedagogy, and technology in effective instruction. In the context of AI, TPACK necessitates that educators possess an understanding of the capabilities of intelligent tools and reframe instructional design to harmonize technological potential with disciplinary knowledge and pedagogical objectives (Mishra & Koehler, 2006). The integration of AI in university-level science education raises an issue of epistemological alignment: how to utilize technology to honor and augment the scientific process, foster genuine inquiry, and enable students as constructors of knowledge.

Ultimately, critical viewpoints – such as those presented by Science and Technology Studies and critical algorithm studies – advocate for prudence in unreservedly adopting AI in educational settings. These viewpoints highlight how AI systems can entrench and replicate existing inequalities, commercialize educational data, and undermine the autonomy of students and educators (Williamson & Eynon, 2020). A comprehensive theoretical examination of AI in science education must be reflexive, addressing both educational possibilities and the sociopolitical aspects of algorithmic decision-making, data governance, and technological reliance.

Collectively, these theoretical frameworks establish a multifaceted basis for examining the potential impact of AI on university-level science teaching. They advocate for a transition from perceiving AI as a neutral facilitator of instruction to recognizing it as a transformational agent that redefines the essence of teaching and learning science in the 21st century.

3. Methods and Materials

The present article is positioned as a theoretical and literature-based study, adopting a dual methodological orientation that draws upon both narrative and integrative review approaches. This combination ensures breadth in capturing diverse perspectives while also providing depth in synthesizing theoretical and empirical insights relevant to the intersection of AI and university-level science education.

From a narrative review perspective, the study does not attempt to be exhaustive in the manner of a systematic review. Instead, it provides a critical and interpretive account of key themes, frameworks, and debates emerging in the scholarly literature. The narrative mode allows for flexibility in selecting and connecting sources across disciplines, thus enabling a reflective discussion of how AI is conceptualized in education, how it interacts with established theories of learning, and how it challenges traditional structures of higher education. Narrative reviews are particularly valuable in fast-evolving domains – such as AI in education – where the pace of technological and conceptual developments exceeds the timeframe required for systematic meta-analyses to stabilize (Greenhalgh et al., 2018).

Complementing this, the integrative review dimension aims to combine insights from a wide range of studies, including conceptual papers, theoretical contributions, and empirical research. Rather than restricting the analysis to a single epistemological stance, the integrative approach enables the identification of cross-cutting themes that bridge science education, educational technology, epistemology, and critical studies of algorithms. By drawing together diverse bodies of literature, this method facilitates the development of a comprehensive and theoretically coherent framework through which AI's transformative role in higher education can be examined. Integrative reviews are particularly suited for constructing new theoretical perspectives, as they allow the researcher to reorganize and reinterpret the literature to highlight emerging paradigms and to address gaps in knowledge (Whittemore & Knafl, 2005).

The sources reviewed were selected based on their relevance to the five thematic

dimensions explored in this article – cognitive, epistemological, pedagogical, institutional, and ethical. While no rigid inclusion or exclusion criteria were applied, preference was given to peer-reviewed journal articles, books, and policy documents published within the last two decades, with special emphasis on works from 2015 onward that reflect the most recent advances in AI and educational theory. Classical references in science education and learning theory were also incorporated where they provided necessary conceptual grounding (Snyder, 2019).

It should be noted that this methodology does not generate new empirical data; rather, it relies on secondary analysis of published research and theoretical contributions. The value of the chosen approach lies in its ability to synthesize dispersed knowledge into a cohesive analytical framework, to highlight conceptual tensions and synergies, and to propose directions for future research and policy. The limitations of the methodology – such as the absence of systematic search protocols and the subjective judgment involved in selecting and interpreting sources – are acknowledged. Nevertheless, this approach is appropriate for the article's aim: to frame AI as a catalyst for rethinking the epistemological, pedagogical, and institutional foundations of science education at the university level.

4. Results

4.1. *AI as a Catalyst: Key Dimensions of Transformation*

AI is not merely a collection of developing technologies; it serves as a catalyst for structural and epistemic reform in higher education scientific curricula. The in-corporation of AI systems in higher education transforms material delivery, knowledge construction, learning assistance, and the organization of educational connections. The possibility for transformation emerges across several interconnected dimensions – cognitive, epistemological, pedagogical, institutional, and ethical – each prompting a reassessment of fundamental assumptions regarding the objectives and methodologies of science education in the 21st century.

At the cognitive level, AI technologies provide innovative avenues for personalized learning, facilitating the customization of instruction according to students' needs, past knowledge, and learning pace. ITS have shown the ability to facilitate profound learning via adaptive feedback, dialogic interaction, and context-sensitive scaffolding. Some authors (Graesser et al., 2018) demonstrated that ITS may replicate expert assistance by including students in iterative questioning, encouraging metacognitive reflection, and detecting misconceptions in real time. These systems offer learners formative feedback loops that can enhance conceptual understanding and self-regulation – skills vital for success in intricate scientific fields. AI-mediated learning environments can significantly alleviate the cognitive strain typically linked to understanding abstract scientific concepts by dynamically tailoring representations, pacing, and feedback to the individual learner's changing requirements.

The epistemological consequences of AI are equally significant. Conventional science education approaches frequently endorse a static perspective of scientific knowledge as a mere assemblage of facts and procedures to be learned and utilized. The incorporation of AI into science education creates potential to convey information as dynamic, data-driven, and probabilistic. In AI-enhanced settings, students can investigate simulations, adjust variables, and model intricate systems utilizing tools that embody modern scientific methodologies. This engagement can enhance learners' understanding of uncertainty, approximation, and evidence-based reasoning. Moreover, the growing application of AI in scientific discovery – encompassing climate modeling, medication development, and astrophysics – necessitates that students be acquainted with the function of algorithms in the generation and analysis of scientific knowledge. The epistemic authority of AI systems should be critically examined rather than passively accepted. Students must cultivate the analytical ability to scrutinize AI outputs, comprehend their limitations, and situate them within wider scientific and ethical contexts (Crawford, 2021).

AI facilitates a transition from traditional transmission-based teaching paradigms to more interactive, inquiry-driven, and student-centered learning approaches. AI technologies can enhance active participation via intelligent simulations, automated scaffolding, and adaptive assessments that deliver quick, individualized feedback. These affordances correspond effectively with constructivist pedagogies and inquiry-based learning, wherein learners are encouraged to explore phenomena, evaluate hypotheses, and collectively generate meaning. Some works (Uttamchandani et al., 2022) assert that the successful orchestration of these settings necessitates an active involvement from educators, who must design,

understand, and respond to learning analytics in pedagogically significant manners. Instead of substituting instructors, AI transforms their job into that of facilitator, interpreter, and architect of intelligent learning environments. Pedagogical competence is crucial for managing the intricate relationship between algorithmic feedback and educational objectives, particularly in fields such as physics, chemistry, or biology, where conceptual understanding and experimentation are vital.

The integration of AI compels colleges to reevaluate the frameworks and mechanisms by which science education is provided. The potential of smart learning environments – characterized by de Jong, Sotiriou, and Gillet (2014) as adaptive, sensor-laden, and context-sensitive spaces – requires institutions to invest in technical infrastructure, interdisciplinary collaboration, and curricular innovation. Conventional course structures and evaluation systems are progressively incongruent with AI-augmented learning, which promotes modular, competency-oriented, and ongoing assessment frameworks. Institutions must formulate new policies for data governance, interoperability, and support services for professors and students. Holmes, Bialik, and Fadel (2019) contend that institutional preparation is a critical factor in determining whether AI will merely enhance current practices or facilitate authentic educational revolution. This preparedness encompasses not only digital capability but also a culture transformation towards innovation, experimentation, and ethical awareness.

The ethical integration of AI in science education extends beyond operational concerns of privacy or data protection, demanding attention to equity, power, and epistemic justice. While AI offers pathways to personalization and efficiency, its uncritical deployment risks exacerbating structural inequities and undermining trust in higher education (Eubanks, 2018; Noble, 2018).

One pressing issue involves algorithmic bias. AI systems built on historical educational data may inadvertently reinforce disparities based on gender, race, language, or socioeconomic background. Predictive analytics tools, for example, have misclassified students from marginalized groups as “at risk,” restricting their access to advanced STEM coursework and perpetuating inequities in science education (Baker & Hawn, 2022). In laboratory-intensive disciplines, biased AI-driven resource allocation could influence access to research opportunities or experimental apparatus.

Another challenge concerns educational surveillance and datafication. AI-based monitoring tools – tracking student engagement through eye movements, keystrokes, or online behavior – risk creating intrusive learning environments that prioritize compliance over curiosity. Such systems disproportionately affect students who may already experience alienation in STEM fields and risk normalizing a culture of surveillance within scientific education (Williamson & Eynon, 2020).

Digital divides further complicate equitable AI integration. Students lacking reliable connectivity or advanced devices may be excluded from AI-supported simulations, virtual labs, or ITS. The COVID-19 pandemic underscored how infrastructural inequalities can translate into learning gaps, particularly in technology-dependent STEM fields (Matsieli & Mutula, 2024).

A deeper concern is the opacity and epistemic authority of AI systems. Many AI applications operate as “black boxes,” providing recommendations without transparency regarding underlying data or algorithms. This undermines one of the central aims of science education: cultivating critical reasoning about evidence and methodology. Over-reliance on opaque AI risks shifting epistemic authority from educators and learners to algorithmic outputs, weakening students’ ability to interrogate and validate knowledge claims (Crawford, 2021).

Addressing these issues requires embedding critical AI literacy within the science curriculum. Students should learn to question AI’s assumptions, assess its outputs, and connect its use to broader socio-technical contexts. This aligns with emerging calls for integrating “algorithmic awareness” as part of scientific literacy, preparing graduates not only to work with AI but also to evaluate its ethical and epistemological implications (Zawacki-Richter et al., 2019). For educators, this entails explicit engagement with frameworks (Blanchard & Taddeo, 2023), which emphasize fairness, transparency, and accountability.

Institutional governance is equally vital. Universities should implement bias audits of AI systems, involve diverse stakeholders in participatory design processes, and provide opt-out mechanisms for students uncomfortable with pervasive monitoring. Ethical safeguards must be treated as foundational, not peripheral, to AI-enhanced education.

By positioning ethics as a central dimension, science education can transform AI from a mere tool into a context for fostering reflexive, critically engaged learners who navigate both

scientific inquiry and its socio-technical implications responsibly. This human-centered approach ensures that AI integration strengthens equity, transparency, and the democratic values underpinning scientific practice.

The five dimensions – cognitive, epistemological, pedagogical, institutional, and ethical – underscore the revolutionary potential of AI in higher education science curricula. However, they also indicate that such transition is not automatic nor devoid of complications. It necessitates a meticulous, theoretically informed, and ethically anchored interaction with the sociotechnical systems now influencing the teaching, learning, and comprehension of science. AI can function as a catalyst, provided that educators, academics, and politicians are equipped to address the intricacies of the issue it poses.

4.2. Emerging Models of AI-Integrated University-Level Science Education

The rise of AI as a pivotal element in educational innovation has prompted a reevaluation of the methodologies employed in teaching and learning science at the university level. AI technologies are now integrated into the central aspects of instruction, moving beyond peripheral activities like grading and administrative optimization. Consequently, innovative forms of science education are emerging – models that are both technologically advanced and pedagogically as well as epistemologically transformative. These approaches signify a shift from the linear, content-centric paradigms of higher science education, advocating for dynamic, interactive, and collaboratively produced learning experiences facilitated by intelligent technologies (Kotsis, 2025; Holmes et al., 2019).

A major shift entails the redefining of the learning environment. AI-enhanced science education frameworks emphasize adaptability and reactivity, forming ecosystems capable of adjusting instructional trajectories in real time according to student behavior, conceptual comprehension, and engagement (Roll & Wylie, 2016). These environments can provide sophisticated scaffolding during experimentation, modeling, or problem-solving tasks. Instead of establishing predetermined learning paths, they enable students to engage in inquiry flexibly while still providing tailored coaching that adjusts to their cognitive requirements. The transition from static curriculum delivery to intelligent mediation facilitates the development of scientific activities, including hypothesis creation, evidence appraisal, and conceptual synthesis – skills sometimes overlooked in conventional lecture formats (de Jong et al., 2014).

A key feature of upcoming AI-integrated models is the customization of education via intelligent conversation and interaction. Contemporary AI systems, especially those enhanced by developments in natural language processing and multimodal analysis, can provide conversational feedback for students, assist them in articulating their reasoning, and encourage metacognitive reflection. These talents facilitate profound conceptual transformation by prompting students to articulate their thoughts, challenge alternate interpretations, and participate in the iterative refinement of ideas (Graesser et al., 2018). Contemporary AI agents, unlike previous pre-programmed tutoring systems, can produce context-sensitive responses that resemble human educational exchanges, however within established limits of accuracy and relevancy. Consequently, they inhabit a novel instructional realm between educator and student – an interlocutor that is neither entirely autonomous nor completely passive.

The redefinition of partnership in scientific education is equally radical. Conventional group work frequently exhibits disparities in involvement and accountability, especially in extensive university environments. AI-integrated models are redefining collaborative learning by including intelligent algorithms that observe group activities, offer real-time assistance, and facilitate the visualization of collective knowledge. These systems can identify when groups diverge in their knowledge frameworks, when communication fails, or when specific viewpoints are suppressed, subsequently initiating actions aimed at maintaining constructive discourse (Uttamchandani et al., 2022). In these circumstances, AI does not supplant collaboration but rather engages as a participant, promoting epistemic equilibrium and inclusivity in the collaborative formation of understanding. This methodology corresponds with modern learning theories that highlight dialogism, distributed cognition, and socially mediated reasoning (Scardamalia & Bereiter, 2014).

At the instructional design level, AI-driven models are disrupting the very framework of the curriculum. Historically, science education has been divided into distinct modules and strict sequences; however, AI facilitates more fluid, nonlinear learning structures. Students may access and depart from learning pathways at various junctures, review concepts through diverse modalities, and interact with knowledge that is adaptively reorganized according to

their performance and interests (Luckin et al., 2016). The flexibility and adaptability afforded by AI facilitate a transition to competence-based curriculum that prioritize transferable scientific reasoning skills over rote procedural knowledge. Furthermore, these technologies assist educators in designing learning experiences that are thematically cohesive and contextually genuine, utilizing real-world data, simulations, and interdisciplinary links.

The educator's function in these models does not reduce; it transforms. In AI-integrated environments, educators have transitioned from being the exclusive transmitters of knowledge to becoming architects of learning experiences, curators of digital resources, and interpreters of student learning pathways. They are tasked with establishing the epistemic atmosphere of the classroom, contextualizing AI outputs, and regulating the ethical and disciplinary parameters governing AI systems (Zawacki-Richter et al., 2019). The efficacy of these new models is contingent upon educators' ability to coordinate intelligent systems in alignment with discipline objectives, honor learner variety, and maintain the integrity of scientific inquiry.

However, these models are not devoid of tensions. The incorporation of AI prompts significant inquiries on epistemic authority, transparency, and the possible diminishment of human judgment in the educational process. As AI systems increasingly assume significant roles in directing scientific reasoning, colleges must remain attentive to the educational and philosophical ramifications of assigning interpretative responsibilities to machines. The degree to which AI systems can or ought to include scientific epistemologies, address uncertainty, or navigate ambiguity is an unresolved and urgent concern (Crawford, 2021). In the absence of critical examination, there exists a danger that these models may unintentionally perpetuate instrumentalist views of science or exclude learners whose cognitive, cultural, or linguistic characteristics deviate from prevailing algorithmic standards.

In conclusion, the nascent models of AI-integrated science teaching are both promising and intricate. They provide a chance to surpass the constraints of conventional instructional design and to cultivate learning environments that are adaptable, dialogic, and epistemically robust. Simultaneously, they require a reassessment of educational roles, beliefs, and expectations. To actualize their revolutionary potential, these models must be grounded in instructional intentionality, theoretical clarity, and a dedication to human-centered learning. Only then can AI serve as a significant collaborator in the redefinition of science education within the university framework.

4.3. Policy and Institutional Implications: Governance, Curriculum, and Faculty Development

The integration of AI into university-level science education necessitates a reconfiguration of institutional policy, governance, curriculum design, and faculty development. AI must be understood not merely as an instructional aid, but as a socio-technical force capable of reshaping how knowledge is organized, taught, and evaluated in higher education. Policies and institutional frameworks must therefore address the pedagogical, ethical, and regulatory dimensions of AI adoption to ensure alignment with quality standards, accreditation requirements, and equity imperatives.

At the governance level, universities must move beyond operational concerns such as procurement or infrastructure and adopt explicit AI governance frameworks that articulate principles of fairness, transparency, and accountability, in line with international guidelines (Blanchard & Taddeo, 2023). These frameworks must address data governance in compliance with regulatory standards such as the General Data Protection Regulation and include mechanisms for the regular auditing of AI systems for algorithmic bias and discriminatory patterns (Williamson & Eynon, 2020). The establishment of interdisciplinary oversight committees involving faculty, students, and external experts can ensure that the deployment of AI aligns with institutional missions and values while safeguarding academic freedom and learner autonomy.

Curriculum reform represents another critical dimension of institutional adaptation. AI integration challenges traditional discipline-bound, linear models of science instruction by enabling modular and competency-based approaches that align with accreditation criteria emphasizing applied skills, interdisciplinary integration, and inquiry-based learning (Holmes et al., 2019). Adaptive learning platforms and intelligent simulations allow for the continuous monitoring of student progress across multiple domains, supporting outcome-driven frameworks such as those articulated in the OECD Learning Compass 2030 and ABET Criterion 3, which prioritize problem-solving, ethical reasoning, and technological adaptability (OECD, 2019). Moreover, embedding AI literacy and critical algorithmic awareness within science curricula aligns with emerging calls for interdisciplinary competence, enabling

students to interrogate the epistemological and ethical implications of AI-mediated knowledge production (Zawacki-Richter et al., 2019). In practical terms, this may involve incorporating modules on AI in scientific practice within physics or chemistry laboratories, thereby linking disciplinary content to the socio-technical realities of contemporary research.

Faculty development is essential for the successful integration of AI in science education. While many science educators possess deep disciplinary expertise, fewer are adequately prepared to navigate the pedagogical and ethical complexities introduced by AI-driven tools (Zawacki-Richter et al., 2019). Professional learning opportunities must therefore move beyond tool-focused training and instead foster advanced competencies in learning analytics interpretation, inclusive instructional design, and ethical engagement with AI. Context-specific programs that support the redesign of laboratory-based courses, simulations, and inquiry activities are crucial to ensure that AI is integrated in ways that uphold scientific rigor and disciplinary authenticity. The development of professional learning communities can further facilitate collaboration among faculty across disciplines, enabling shared reflection on AI-enhanced pedagogical practices and fostering institutional cultures of innovation and continuous improvement.

Equity considerations are central to the institutional adoption of AI. Without deliberate attention to issues of access and inclusion, AI risks exacerbating existing disparities in science education. Studies during the COVID-19 pandemic highlighted how infrastructural inequalities, such as limited broadband access or inadequate devices, disproportionately affected students from low-income and marginalized backgrounds, restricting their participation in digitally mediated learning environments (Matsieli & Mutula, 2024). Universities must therefore implement policies that provide equitable access to necessary hardware, connectivity, and AI-supported laboratory resources, while also ensuring compliance with universal design principles to accommodate students with disabilities. Participatory approaches involving students in the evaluation and selection of AI platforms can further embed inclusive perspectives into institutional decision-making and mitigate the risk of exacerbating structural inequities.

Ultimately, the policy and institutional implications of AI integration in science education must be situated within broader frameworks of accreditation and quality assurance. Accrediting bodies such as ABET and the European Standards and Guidelines for Quality Assurance in Higher Education increasingly emphasize transferable skills, ethical literacy, and interdisciplinary knowledge as hallmarks of high-quality programs. Aligning AI adoption with these frameworks ensures that innovation in science education is not driven by technological novelty alone but remains anchored in pedagogical intentionality, epistemic integrity, and equity-focused governance. Such alignment positions AI not as a disruptive imposition but as a catalyst for strengthening the scientific, ethical, and civic purposes of higher education in an increasingly algorithmic world.

5. Discussion

The incorporation of AI into university science teaching necessitates more than mere technological implementation; it calls for a fundamental reevaluation of the epistemological, pedagogical, and institutional structures that have historically supported higher education. As illustrated in earlier sections, AI has offered a novel array of affordances that contest the conventional limits of education, assessment, and curriculum. The revolutionary potential of AI relies more on the interpretations, designs, and implementations by educational stakeholders than on the technology's inherent capabilities, within wider cultural, institutional, and epistemic frameworks.

The integration of AI has significantly altered the epistemology of science education. Traditionally, university-level science education has favored a perspective of knowledge as fixed, abstract, and hierarchically organized – an understanding frequently bolstered by lecture-centric teaching, summative assessments, and content-laden curricula. AI, especially in its data-driven and probabilistic manifestations, undermines this perspective. It exposes learners to real-time modeling, simulation-based reasoning, and interactive data exploration, emphasizing the contingent, iterative, and contextual aspects of scientific inquiry (Kotsis, 2025). This re-orientation compels educators to adopt a more dynamic conception of science as a practice of meaning-making and model-building, rather than simply an aggregation of data. In this regard, AI presents a chance to better connect university-level education with genuine scientific epistemologies, which are defined by ambiguity, collaboration, and revision.

Furthermore, AI necessitates a reassessment of pedagogy itself. The traditional concept

of teaching as material delivery is becoming increasingly impractical in learning contexts where students can obtain tailored explanations, feedback, and problem sets via intelligent computers. The educator's responsibility shifts to mediation and design, creating learning experiences that facilitate students' critical engagement with both discipline content and the AI systems that provide it (Uttamchandani et al., 2022). This transition necessitates educational flexibility and conceptual profundity. It urges educators to traverse a novel didactic triangle – comprising student, content, and intelligent system – where agency is distributed and authority is redefined. In this setting, teaching necessitates not only digital literacy but also an enhanced pedagogical imagination that can foresee the novel modalities of cognition and collaboration enabled by AI.

Universities must advance beyond pilot initiatives and isolated inventions to develop a comprehensive strategy for AI-enhanced science teaching. This encompasses investment in infrastructure, collaborative design teams, and long-term evaluation systems that assess not only technological adoption but also pedagogical transformation. Nonetheless, the danger is in organizations perceiving AI only as a neutral productivity instrument instead of recognizing it as an educational entity with significant normative consequences. In the absence of critical monitoring, AI systems may reinforce existing hierarchies, surveil behavior in ways that stifle creativity, or marginalize learners whose cognitive profiles diverge from prevailing algorithmic assumptions (Crawford, 2021). Universities must consequently take responsibility not only for the operational efficacy of AI technologies but also for the ideals and assumptions these tools embody. This necessitates methods for ethical governance, participatory design, and inclusive review processes that prioritize the perspectives of learners and instructors.

The integration of AI in science education creates a fundamental conflict between customization and collectivism. Although adaptive learning environments offer personalized education, the discipline of science necessitates collective frameworks, communal validation of information, and public reasoning. The objective is to develop AI systems that promote personal development while maintaining epistemic discourse and societal responsibility. This is particularly crucial during a period when public confidence in research is strained, and the ability to participate in scientific discourse and critique is vital for informed citizenship. AI should not serve as a tool for intellectual seclusion; instead, it ought to be utilized to facilitate collaborative exploration, enhance mutual comprehension, and promote communal problem-solving.

The discourse highlights the transforming identity of the science educator in the era of AI. STEM faculty are increasingly obligated to participate in instructional activities that extend beyond core knowledge, encompassing learning analytics, digital ethics, curriculum innovation, and interdisciplinary discourse. This emerging professional environment is characterized by both potential and instability. AI can enable instructors to explore innovative methodologies, provide immediate insights into student learning, and create more inclusive environments. Conversely, it may impose unexpected requirements, elevate cognitive burden, and obscure the distinctions among teaching, data science, and educational technology. Facilitating educators during this transition is not merely an issue of optional training but a question of institutional equity. In the absence of organized assistance, AI may exacerbate the existing strain within an already overstretched academic framework.

This reevaluation of university-level science education must be contextualized within over-arching inquiries of educational objectives. What type of scientific graduates do we aspire to develop in an AI-dominated environment? In addition to mastering information, students must cultivate the ability to critically evaluate the tools they utilize, the knowledge they produce, and the systems they engage with. AI integration provides a means to incorporate reflexivity, ethics, and epistemic humility into the science curriculum – attributes essential for addressing complicated, uncertain futures. To actualize this promise, scientific education must reject the allure of automation and instead use AI as a means to foster human agency, curiosity, and accountability.

In conclusion, the discourse indicates a future where AI is neither a panacea nor a menace, but a transformative force that can assist educators and institutions in redefining the essence of science education. The inquiry is not if AI will influence science education, but rather how we will facilitate its incorporation. This necessitates bravery to challenge established beliefs, ingenuity to formulate innovative frameworks, and dedication to prioritizing learning as a fundamentally human pursuit – even in collaboration with intelligent computers.

While this paper offers a theoretically grounded analysis of AI as a catalyst for transformation in university-level science education, it is important to acknowledge its limitations.

As a conceptual and literature-based study, it does not present empirical data or case studies demonstrating AI's implementation in specific university contexts. This absence of empirical validation restricts the capacity to assess how the proposed frameworks and ethical considerations manifest in real-world instructional settings, particularly across diverse institutional and cultural contexts. Future research should therefore focus on systematically examining AI integration through longitudinal, mixed-methods studies that capture both learning outcomes and the socio-technical dynamics within classrooms and laboratories.

Another limitation lies in the generalization of AI applications across the broad spectrum of scientific disciplines. Although the article references examples from physics, chemistry, and related fields, disciplinary differences in epistemic practices, laboratory infrastructure, and pedagogical traditions may influence how AI is adopted and perceived. Comparative studies examining discipline-specific implementations are essential for understanding how AI tools align with varied scientific epistemologies and instructional demands.

Furthermore, while the discussion addresses ethical issues such as bias, surveillance, and equity, it does so primarily from a theoretical perspective. Future work should incorporate empirical evaluations of governance frameworks and bias mitigation strategies within higher education institutions. This includes investigating how policies based on standards (Blanchard & Taddeo, 2023) or ABET accreditation criteria translate into practice, and how they influence student and faculty perceptions of AI trustworthiness and legitimacy.

Finally, the rapid evolution of AI technologies introduces an inherent challenge for scholarship in this area. Emerging systems such as generative AI, multimodal learning environments, and adaptive laboratory simulations demand ongoing inquiry to ensure that research and policy keep pace with technological innovation. Future studies should prioritize participatory design methodologies, involving students, educators, and policymakers in co-constructing AI-enhanced science education ecosystems that balance technological affordances with humanistic, ethical, and disciplinary values.

6. Conclusions

The transformational promise of AI in higher education science lies not only in its technological capabilities but also in its ability to instigate profound systemic change across epistemological, pedagogical, and institutional aspects. This article contends that AI should not be viewed as a mere enhancement or transient phenomenon, but as a fundamental force that necessitates science educators, curriculum designers, and policymakers to reevaluate core assumptions regarding the teaching, learning, and valuation of knowledge.

The use of AI into science education challenges conventional teaching methods based on linear presentation, disciplinary isolation, and passive absorption of information. It promotes novel kinds of student agency through ITS, adaptive learning environments, and learning analytics, facilitating personalized, interactive, and inquiry-based learning experiences. Nonetheless, as these technologies infiltrate educational environments, they reveal inherent tensions – between automation and human discernment, customization and shared knowledge, efficiency and contemplation. The implementation of AI should be directed by a conscious educational and ethical framework based on ideals of justice, inclusivity, and scientific integrity, rather than by technological determinism.

The ramifications reach well beyond the classroom. Universities must establish governance structures at the policy level that guarantee transparency, equity, and accountability in AI application. Curricular reforms should be grounded in genuine scientific procedures and interdisciplinary consistency, rather than in the mere allure of innovation. Professional development must enable educators to critically engage with AI tools, rather than simply utilize them, and to actively partake in their design and assessment. The educator's position is thereby redefined – not reduced, but augmented – to encompass the functions of designer, mediator, interpreter, and ethical steward.

The future of AI in science education will be determined not just by advancements in algorithms and interfaces but also by the collective decisions of educational communities. A critical necessity exists for interdisciplinary discourse, collaborative design, and extended research that focuses on both the advantages and the obstacles of AI integration. The crucial inquiry is no longer if AI will transform science education, but rather how we can guarantee that this transformation enhances learning, democratizes access, and upholds the humanistic objectives of education.

As the distinctions among learners, machines, and knowledge systems become more fluid, the university science classroom must transform into an environment where students

not only gain disciplinary knowledge but also learn to navigate, critique, and influence the algorithmic frameworks of the 21st century. In this regard, AI transforms from merely an instructional tool to a framework for re-envisioning the entire endeavor of science education – promoting more equitable, reflective, and progressive pedagogical approaches.

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